ARKIV FÖR FYSIK Band 11 nr 15

Communicated 6 June 1956 by Erik Hulthén

On the phase and the amplitude of cosmic ray diurnal variation

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With 4 figures in the text

Abstract

The diurnal variation in cosmic ray intensity has been measured at the geophysical station in Kiruna with a Geiger-Müller counter set comprising three counter-telescopes, one pointing to the zenith and two pointing east and west respectively with zenith angles of 30°. It appears that the phase and amplitude of C.R. intensity variation has varied during the period 1 January 1954 to 23 March 1955. The registrations also indicate that the average momentum of C.R. is about 3×10^{10} eV/c.

The original direction of C.R. before being deflected in the magnetic field of the Earth has been constructed for the three directions zenit, west and east, keeping in mind the fact that the momentum varies.

Introduction

The diurnal variation of C.R. has been studied by many scientists. Malmfors [1] found the varying component of C.R. to be between 0.5 % and 0.3 % of the average (0.3 % during days with little solar activity and 0.5 % during disturbed days). A maximum occurred between 1200 h and 1400 h. Elliot and Dolbear [2] found a varying component of 0.2 % of the average and a maximum occurring about 1400 h in the south-pointing telescope and about 1130 in the north-pointing telescope.

Telescopes used in earlier investigations have had large opening angles and a correspondingly high counting rate. In order to get a more exact geometry of the telescope and to try to get higher precision in determining the direction of C.R., the telescopes in Kiruna were constructed with narrow opening angles. The one pointing to zenith opened 24°, and the telescopes pointing east and west at 30 zenith degrees opened 20° each. Depending on the length of the GM-tubes each telescope had a north:south opening angle of 120°.

The zenith telescope counted 16000 coincidences per hour and the others counted 10000 coincidences per hour. To keep the statistical uncertainty within acceptable limits it is necessary to evaluate the means of registrations of three or four months, as the fluctuations follow Poisson's law.

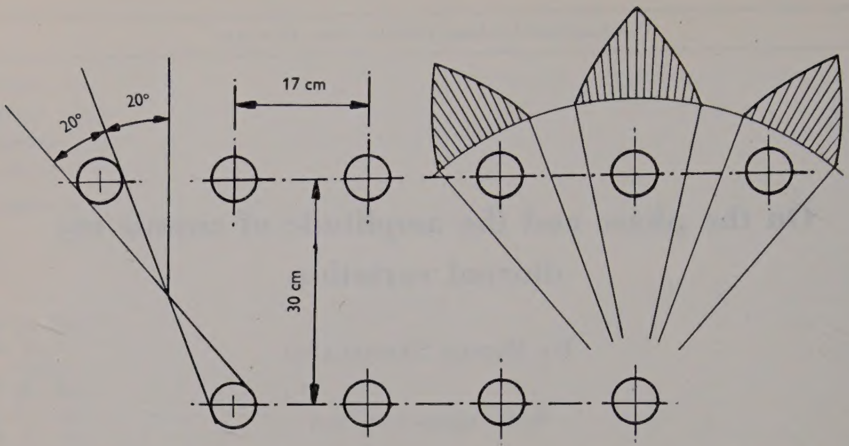


Fig. 1. Arrangement of the GM tubes. The shadowed diagrams over the tubes show the surface of the channels, exposed to the radiation, plotted against the angle of incidens, and give an image of the selectivity in the east–west direction.

Experimental details

The apparatus used consisted of ten GM-tubes made of brass (diam. 6 cm, length 60 cm). They were filled with an argon alcohol mixture (1 cm C_2H_5OH and 6.5 cm Ar) and operated at a stabilized voltage of 1400 volts. The plateaux have been about 100 volts. The tubes were arranged as shown in Fig. 1 and worked in twelve coincidence sets or channels. The pulses in each tube were cut off by a uni-vibrator quenching curcuit as quickly as possible. The number of coincidences in each channel was recorded separately by a scale of four and a mechanical recorder. For the sake of simplicity all electrontubes were of the same type (12 Au 7).

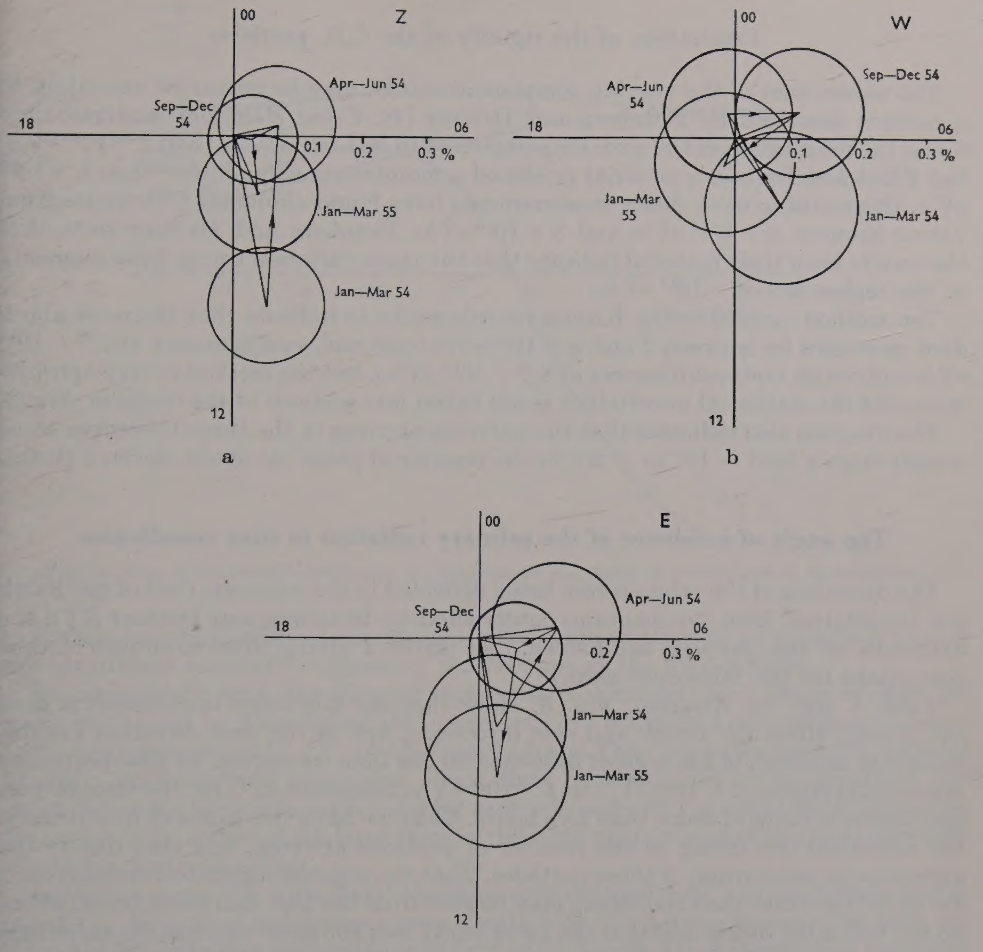
The proper working of the channels was checked by comparing the diagrams of the twelve day-recordings. When one channel dropped in recording intensity or climbed to higher numbers of coincidences compared to the other channels, it was possible to correct without stopping or disturbing the rest.

The recorders together with a recorder for interruptions of the main supply, an hour-recorder and a datum-recorder were photographed each hour. The apparatus was placed in a concrete building sunk in the ground some hundred meters away from other buildings. The radiators were placed between the stone walls and the inner wooden walls, and the temperature kept constant within ± 0.5°C. The cosmic laboratory is part of the geophysical station in Kiruna (68° N, 20° E and 65° geomagn. lat.).

The treatment of the material followed the system described by Malmfors. The barometric coefficient $-0.17\,\%$ per mB and the standard pressure of 960 mB have been used. The mean diurnal variation has been obtained by analysing recordings from channels approved through the control system over a period of at least three months.

Variation in the phase of the diurnal variation

Earlier measurements of the C.R. diurnal variation have shown that the phase of the variation in one direction has altered from one year to another. It is suggested



a

b

c

Fig. 2 a–c. Harmonic dials of the time of maximum and the amplitudes during the four periods.

that the time of the occurrence of maximum C.R. reaching the Earth varies over a period of about 22 years or twice the period of the sunspot-minimum years. It has not yet been possible to measure the period. Thambyahpillai and Elliot [3] show that the maximum occurred about noon in the year 1933 and that subsequently its occurrence was later, about 1500 h in the year 1944. In 1952 the maximum again occurred about noon.

In Kiruna the maximum during the period 1 January 1954 to 23 March 1955 first occurred about noon, then earlier in the morning, and finally a little before noon. In the zenith and east directions the amplitude was also less during the period April–December 1954 than during the periods January–March 1954 and January–March 1955. See Fig. 2.

Estimation of the rigidity of the C.R. particles

The momentum of the varying component of C.R. may be estimated according to a method described by Brunberg and Dattner [4]. Using Malmfors' material they found the momentum of the variable component to be a little more than 2×10^{10} eV/c, but Elliot and Dolbear's material produced a momentum value higher than 3×10^{10} eV/c. Others using more direct measurements have found abundant C.R. momentum values between 2×10^{10} eV/c and 3×10^{10} eV/c. Brunberg and Dattner state that the results from their material indicate that the main variation comes from momenta in the region 2 to 4×10^{10} eV/c.

The method applied to the Kiruna records seems to indicate that the most abundant momenta lie between 2 and 5×10^{10} eV/c (east and west intersect at 2.7×10^{10} eV/c and zenith and east intersect at 4.7×10^{10} eV/c), but the method is very approximate and the statistical uncertainty is not taken into account in the diagram, Fig. 3.

The diagram also indicates that the particles arriving in the three telescopes come mainly from a field $-10°$ to $-20°$ in the equatorial plane (or about eleven o'clock).

The angle of incidence of the primary radiation in time coordinates

The directions of the orbits before being deflected in the magnetic field of the Earth can be obtained from the diagrams constructed by Brunberg and Dattner [5] if the momenta of the particles are known. (See Table 1 giving three examples of time corrections for the telescopes used.)

Table 1 and the diagram, Fig. 3, show that the difference in momentum does not greatly affect the zenith and east directions, but in the west direction the difference in momentum has a great influence on the time correction. In that particular momentum region, 2×10^{10} eV/c to 4×10^{10} eV/c, abundant in C.R., the time correction makes a jump of more than five hours. Thus we have two kinds of uncertainty: the statistical one owing to the number of particles arriving, and that due to the difference in momentum of these particles. That the registrations in the west direction are more uncertain than the others may be seen from the fact that these registrations do not follow the others and that the uncertainty is of the same value as the amplitude of the variations. The west direction is not represented in Fig. 4, where the variation in phase is plotted against the time.

For comparison the partly simultaneous values from registrations in Stockholm are given in Table 2. It is obvious that the time of maximum has varied in Stockholm as

Table 1. Correction values for the angle of incidence of primary particles with momenta 2, 3, and 4×10^{10} eV/c.

Final direction at the surface of the earth	Time correction for momentum 2×10^{10} eV/c	Time correction for momentum 3×10^{10} eV/c	Time correction for momentum 4×10^{10} eV/c
Zenith	+ 2 h 15 min	+ 2 h 15 min	+ 2 h
30 Z-degrees W	+ 3 h 15 min	+ 2 h 45 min	− 2 h
30 Z-degrees E	+ 1 h 45 min	+ 2 h 15 min	+ 2 h 45 min

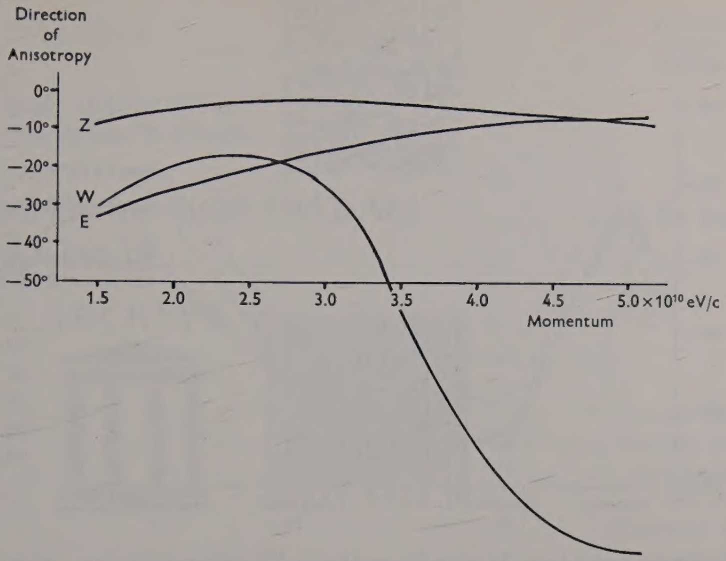


Fig. 3. The direction of anisotropy in the equatorial plane as a function of momentum.

in Kiruna but the statistical uncertainty is too large to allow us to get a clear idea of the magnitude especially concerning the last one of the four periods.

Simultaneously with the Kiruna registrations, Sarabhai and his coworkers [6] made recordings in Ahmedabad (10° geom. lat.) in a counterset comprising telescopes with opening angles of 5°, 10°, and 30° respectively. They have also recorded the total intensity striking their telescopes. From their material they have calculated the mean values for the whole period and for each telescope. In two small angle telescopes maximum C.R. occurred 1 h later than in the large angle one, and the total intensity maximum was still earlier.

In the telescope ^{15}T, with about the same opening angle (30°) as the Kiruna zenith one (24°), the time of maximum agrees closely with the Kiruna values when both are corrected for deflection in the magnetic field of the Earth. Fig. 4 shows these corrected times for the momenta 2×10^{10} eV/c and 4×10^{10} eV/c.

The amplitude of the variations differs very much, however, (0.08 ± 0.04 % in Kiruna; 0.96 ± 0.08 % in Ahmedabad), probably partly owing to the different con-

Table 2. Variations of the time of maximum in the zenith direction in Stockholm (58 geom. lat.) corrected for deflection in the magnetic field, for two particle momenta.

		2×10^{10} eV/c	4×10^{10} eV/c	Amplitude in per cent
1954	1 Apr.–30 June	0800	0815	$0.14 \pm 0{,}08$
1954	1 July–30 Sept.	0545	0600	0.18 ± 0.08
1954	1 Oct.–31 Dec.	1230	1245	0.16 ± 0.10
1955	1 Jan.–6 Mar.	1030	1045	0.09 ± 0.10

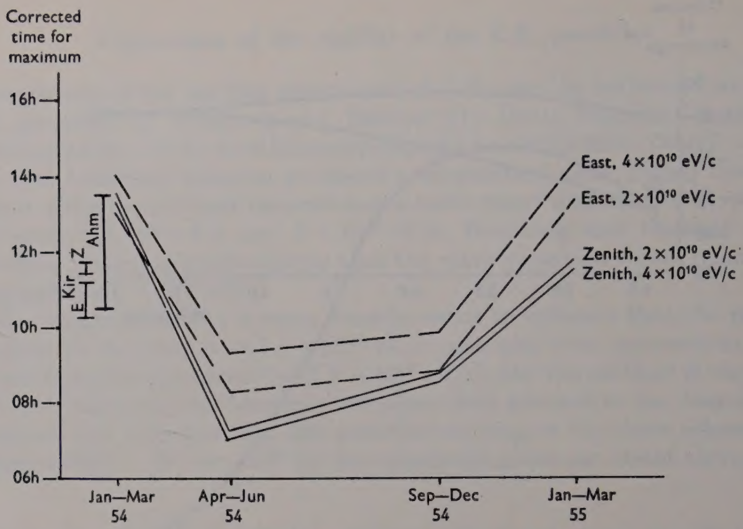


Fig. 4. The diagram shows how the time for maximum CR has varied during the period January 1954–March 1955. Corrections have been made for deflection in the magn. field of earth. The momenta of 2×10^{10} eV/c and 4×10^{10} eV/c have been used. To the left the mean values for the whole period are plotted for Kiruna East, Kiruna Zenith and Ahmedabad Zenith.

struction of the respective apparatuses and partly owing to the different latitudes. The C.R. cut-off momentum is in Kiruna for all directions about 0.01×10^{10} eV/c, whereas in Ahmedabad these momenta are respectively 1×10^{10} eV/c, 1.3×10^{10} eV/c and 2.4×10^{10} eV/c, in the three directions 45 zenith degrees *W*, zenith and 45 zenith degrees *E*. Thus the radiation in Ahmedabad is harder than in Kiruna. Moreover, the telescopes in Ahmedabad were shielded with 12 cm of lead.

ACKNOWLEDGEMENTS

I am indebted to the Swedish Natural Science Research Council and to the board of Vetenskapsakademins forskningsstationer i Övre Norrland for providing the facilities for this work. I also thank Mr. Karl Erik Heikkilä, the caretaker at the laboratory, Mr. Sven Olof Larson and Miss Ulla Björkegren for their help.

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Tryckt den 6 november 1956

Uppsala 1956. Almqvist & Wiksells Boktryckeri AB